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journal or publication title	BULLETIN of THE NATIONAL AGRICULTURAL RESEARCH CENTER for WESTERN REGION
volume	11
page range	15-25
year	2012-02-28
URL	http://doi.org/10.24514/00001724

doi: 10.24514/00001724

Bull. NARO West. Reg. Agric.
Res. Cent. 11：15－25，(2012)

Effect of Grass Hay Feeding on Meat Production, Carcass Characteristics, and Meat Quality in Japanese Black Steers

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Key words： beef cattle, grass hay, carcass characteristics, meat quality, fatty acid, water-holding capacity

Contents

(Received December 7, 2011)

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Ⅰ Introduction

The annual report on food, agriculture, and rural area in Japan[13] has described that the food self-sufficiency rate in Japan is the lowest among advanced nations. Furthermore, the feed self-sufficiency rate for livestock production in Japan is low among advanced nations because most concentrate diets depend on foreign countries. The national government of Japan estimates that improvement in the feed self-sufficiency rate would lead to an increase in the food self-sufficiency rate. The national and local governments of Japan are promoting the utilization of rice fields, abandoned cultivated land, and grazing for livestock production. But most beef cattle in Japan are reared individually in free stanchion barns and are generally finished indoors on a concentrate-based diet throughout the fattening period until slaughter. The studies of beef cattle production have made use of grazing and roughage in the field. A previous study showed that the final body weight, daily gain, and energy intake of steers reared by restricted feeding of concentrate and roughage *ad libitum* were lower than those of steers reared by feeding of concentrate *ad libitum*[15]. Crude protein content and drip loss in meat were higher for grazed cattle than for concentrate-fed cattle in free stanchion barns, and the beef marbling standard (BMS) number and crude fat content in meat were lower in grazed cattle than in concentrate-fed cattle[23]. The α-tocopherol and β-carotene contents in the muscle of pasture-fed Japanese Shorthorn steers were higher than those of concentrate-fed steers, and pasture finishing decreased the drip loss of the beef[16]. In contrast, the drip loss of the meat was shown to be no different between concentrate-fed steers and grazed steers[7]. Furthermore, pasture-fed cattle undergo greater change in the fatty acid composition of the meat compared with that in indoor concentrate-fed cattle[12, 16].

In terms of the effects of roughage on beef production, although several comparisons between outdoor-grazed and indoor concentrate-fed steers have been reported, there are few comparisons of grass-fed and concentrate-fed steers that are kept indoors. The objective of this study was to investigate the effect of indoor feeding of large amounts of roughage on the characteristics of the beef and meat quality.

Ⅱ Materials and Methods

1 Animal Management

Management of steers and all procedures in this study were performed according to the Animal Experimental Guidelines of the NARO Western Region Agricultural Research Center (NARO/WARC), Japan. Twelve Japanese Black steers aged 10 months that had been bred at NARO/WARC were randomly divided into two groups: a hay-fed group and a concentrate-fed group. All steers were housed individually in a stall barn and fed grass hay (59% total digestible nutrients [TDN] and 7.2% crude protein [CP] on a dry matter basis) at 1.5 kg/day and concentrate (flaked corn, flaked barley, wheat bran, and soybean meal; 73% TDN and 11% CP) *ad libitum* from 10 to 16 months of age. After this control period, the hay-fed group (n = 6) was switched to an experimental diet that consisted of grass hay *ad libitum* and concentrate at 2.0 kg/day in the stall barn; in contrast, the concentrate-fed group (n = 6) was fed concentrate *ad libitum* and grass hay at 1.5 kg/day in the stall barn. The TDN intakes were calculated from feed intakes and TDN of each diet. The steers were slaughtered at 28 months of age, and skeletal muscle tissue from the *M. semitendinosus* (ST) and *M. longissimus lumborum* (LL) was obtained for analysis.

2 Carcass Evaluation and Sample Preparation

Carcasses were kept in a refrigerator at 0℃ for 24 h; they were then evaluated by their dressing percentage and by measurement of the BMS, beef fat color standard (BFS), beef color standard (BCS), rib eye area, rib thickness, and subcutaneous fat thickness of the section between the sixth and seventh ribs according to the Japanese New Beef Carcass Grading Standards[10]. Muscles were removed from the carcasses to analyze meat characteristics such as the drip loss, cooking loss, and Warner-Bratzler shear force (WBSF). The muscles were processed into 2.5-cm (thickness) steaks, vacuum-packed, stored in a refrigerator at 2℃ for 2 and 30 days after slaughter, and frozen at -80℃ until analysis.

3 Nutrient Contents in Muscle

Muscle tissues were minced to determine the crude protein and extractable lipid contents and fatty acid composition. Crude protein was calculated by quantitative analysis of nitrogen using the Kjeldahl method with copper sulfate and potassium sulfate as catalysts[1]. Lipid was extracted with diethyl ether for 16 h using a Soxhlet extractor[1]. To analyze the fatty acid composition in the muscle tissue, the extracted lipid was converted to fatty acid methyl esters by boron trifluoride methanol complex methanol solution and analyzed using gas chromatography[2].

4 Meat Characteristics

Steaks were thawed for 24 h at 4℃ and then carefully mopped dry using paper tissue. Drip loss was calculated from the weight difference between before and after storage[16]. Following the measurement of drip loss, the samples were broiled on electric grills to an internal temperature of 70℃; they were then wrapped in plastic to prevent desiccation and stored at 4℃ for approximately 12 h[14, 19]. Cooking loss was calculated from the weight difference between before and after cooking[14, 16]. Six cores (1.3 cm in diameter) were removed from each steak parallel to the longitudinal orientation of the muscle fibers[14, 19]. All cores were sheared using a WBSF machine, and the peak shear force was recorded. In the present study, only the drip loss and cooking loss were employed as indices of water-holding capacity.

5 Statistical Analyses

All measurements are presented as means ± SEM. The relationships between the measurements of the hay-fed group and the concentrate-fed group were analyzed using one-way ANOVA and a post hoc Fisher's test. Statistical significance was defined as $p < 0.05$.

Ⅲ Results and Discussion

1 Growth Performance and Carcass Characteristics

Growth performance and carcass characteristics of hay-fed and concentrate-fed steers are shown in Table 1. Although all steers had a similar body weight (initial and middle body weight) at 10 and 16 months of age, final body weight and daily gain were significantly higher in the concentrate-fed group than in the hay-fed group. There was no significant difference in the TDN intake between the two groups during the control period. In contrast, during the experimental period, the TDN intake from grass hay was significantly higher in the hay-fed group than in the concentrate-fed group. In addition, the TDN intake from concentrate during the experimental period in the hay-fed group was significantly lower than that in the concentrate-fed group. The total TDN intake of both diets of the concentrate-fed group was significantly greater than that of the hay-fed group during the experimental period. Steers reared by restricted feeding of concentrate and *ad libitum* roughage had significantly lower slaughter body weight, carcass weight, and TDN intake than did steers reared by feeding concentrate *ad libitum*[15]. This suggests that the lower final body weight and daily weight gain was more attributable to lower TDN intake in the hay-fed group than in the concentrate-fed group.

The half-dressed carcass weight, rib eye area, and rib thickness were significantly less in the hay-fed group than in the concentrate-fed group, but the dressing percentage, BMS, BFS, BCS, and subcutaneous fat thickness were not significantly different between the groups (Table 1). Several studies found decreased marbling scores and dressing percentages when Japanese Black multiparous cows[23] and Brahman[3] and Angus[18, 22] steers were fed a large amounts of roughage. In contrast, another study reported that Japanese Black steers fed a combination of roughage *ad libitum* and restricted feeding of concentrate showed no differences in dressing percentage or BMS compared with the concentrate *ad libitum*[15]. In these several reports, beef marbling and dressing percentage (*i.e.*, meat quality and quantity) showed inconsistent results among different breeds and sexes. BMS and dressing percentage in this study coincided with those in the

Table 1. Growth performance and carcass characteristics of steers fed grass hay or concentrate

	Grass hay	Concentrate
Body weight (BW), kg		
Initial (10 month)	286±10.5	283±7.1
Middle (16 month)	484±14.3	482±14.5
Final (28 month)	615±19.3	729±28.8*
Daily gain (DG), kg/day (10-28 month)	0.59±0.02	0.79±0.05*
TDN[1] intake, kg/day		
Control period (10-16 month)		
Grass hay	0.73±0.09	0.63±0.03
Concentrate	4.53±0.13	4.27±0.09
Grass hay + concentrate	5.26±0.20	4.90±0.11
Experimental period (16-28 month)		
Grass hay	3.36±0.13	0.82±0.05*
Concentrate	1.79±0.03	6.37±0.25*
Grass hay + concentrate	5.15±0.11	7.19±0.29*
Carcass characteristics		
Half dressed carcass weight, kg	175±4.7	227±8.6*
Dressing percentage, %	71.1±0.23	71.8±0.44
BMS[2], No.	3.3±0.4	3.8±0.5
BFS[3], No.	2.3±0.3	2.3±0.3
BCS[4], No.	4.2±0.2	3.7±0.4
Rib eye area, cm^2	34.6±1.3	44.4±2.4*
Rib thickness, cm	5.1±0.2	7.0±0.2*
Subcutaneous fat thickness, cm	2.1±0.3	2.7±0.3

1) TDN: total digestible nutrients, 2) BMS: beef marbling standard,
3) BFS: beef fat color standard, 4) BCS: beef color standard
Values are expressed as means ± SEM. *$p < 0.05$

previous study[15] but did not correspond to those in other studies[3, 18, 22, 23], likely because of different breeds and sexes. The present study suggests that hay-fed steers do not undergo changes in meat quality characteristics such as BMS, BFS, and BCS, but that they undergo decreases in meat quantity because of reductions in daily gain.

In terms of meat productivity, when the cattle were offered either a low- or high-treatment pelleted ration (barley and alfalfa) for 20 weeks, body weight gain (BWG) of the low-treatment cattle was less than that of the high-treatment cattle[9]. However, continuous grazing of these cattle resulted in an increase in BWG of the low-treatment cattle compared with that of the high-treatment cattle. They suggested that this result was caused by compensatory growth. Furthermore, we have suggested that compensatory growth would have started at the end of fattening by changes in myosin heavy chain and myostatin gene expressions when steers were fed a large amount of roughage during the indoor fattening period (the same as the rearing system of the present study)[21]. Although fattening was completed at 28 months of age in the present study, compensatory growth might be caused by continuous rearing of grass hay fed to steers. Further study is necessary to elucidate this phenomenon.

2 Meat Quality and Nutrient Contents in Muscle

Table 2 shows the nutrient contents in the LL and ST muscles of the hay-fed and concentrate-fed steers. A previous study reported that the protein content in muscle was lower in grass-fed cattle than in cattle fed a combination of grass and concentrate[22]. In contrast, no difference in protein content was found in the *longissimus* muscle between steers fed both concentrate and a large amount of roughage and steers fed concentrate[8, 20]. Consistent with these reports, we found no difference in protein content in the LL muscle samples of the two groups (Table 2). However, crude protein content in the ST muscle was significantly higher in the hay-fed group than in the concentrate-fed group. Extract lipids in the ST and LL muscles were higher in the concentrate-fed group than in the hay-fed group (p = 0.08 and 0.06, respectively), although there was no significant difference between the groups (Table 2). Several previous reports have described a lower intramuscular fat content in grass-fed[15], pasture-fed[16], and forage-fed[20] steers compared with that in

Table 2. Nutrient contents, water-holding capacity, and Warner-Bratzler shear force in the *M. longissimus lumborum* (LL) and *M. semitendinosus* (ST) muscles of steers fed grass hay or concentrate

	LL		ST	
	Grass hay	Concentrate	Grass hay	Concentrate
Crude protein, %	19.4±0.65	17.6±0.75	21.0±0.31	20.0±0.26*
Extract lipid, %	15.5±2.6	24.0±3.2^{+}	6.30±1.2	9.70±1.2^{+}
Drip loss, %	2.98±0.94	2.17±0.29	2.30±0.33	5.14±0.94*
Cooking loss, %				
2 day	39.1±1.44	38.3±1.19	40.5±1.05	41.1±0.82
30 day	36.8±0.71	39.1±1.23	38.6±0.76	40.9±0.69^{+}
Share force, kg				
2 day	3.1±0.56	2.1±0.17^{+}	5.0±0.60	3.3±0.14*
30 day	1.9±0.33	1.6±0.11	3.1±0.22	2.6±0.09^{+}

Values are expressed as means ± SEM. *p < 0.05, ^{+}p < 0.10

concentrate-fed steers. In contrast, other studies report that the muscle lipid content was not statistically different between grass-fed and grain-fed steers[8, 22]. These results suggest that steers fed a large amount of grass hay leads to an increase in skeletal muscle protein content and a decrease tendency in intramuscular fat accumulation compared with those in concentrate-fed steers.

The water-holding capacity of meat has important influences on the drip loss and cooking loss of meat. Drip loss in the ST muscle was significantly lower in the hay-fed group than in the concentrate-fed group, though that in the LL muscle was not significantly different between the groups (Table 2). Similarly, lower drip loss has been reported for meat from grass-fed[8] and pasture-fed[16] steers compared with that from concentrate-fed steers. On the other hand, several reports describe no difference in drip loss between concentrate-fed steers and either grazed[7] or alfalfa silage-fed[11] steers. These reports revealed that it may be difficult to obtain a constant result for the drip loss because of slight changes in rearing systems or differences in animal backgrounds. Cooking loss in the ST muscle was not different between groups at 2 days after slaughter; however, it was significantly lower in the hay-fed group than in the concentrate-fed group at 30 days after slaughter (Table 2). In contrast, a previous study reported that cooking loss in muscle is lower in concentrate-fed bulls than in grazed bulls[7]. Furthermore, several reports describe no difference in cooking loss between concentrate-fed steers and alfalfa silage-fed[11] or grass-fed[8] steers. It may also be difficult to obtain a constant result for cooking loss because of slight changes in rearing systems or differences in animal backgrounds. In the present study, although the cooking loss in muscle was not consistent with any previous reports on roughage-fed steers, the results for both drip loss and cooking loss suggest that the water-holding capacity of steers may be improved by indoor feeding of a large amount of grass hay.

The WBSF is used to measure meat tenderness[4] and is probably the most commonly used globally. The WBSF in the ST muscle was significantly higher in the hay-fed group than in the concentrate-fed group at 2 days after slaughter (Table 2). The shear force of muscle from concentrate-fed steers is lower than that from forage-fed[20] and pasture-fed[16] steers. In terms of factors that influence shear force, a previous study reported that shear force is low in muscle with high crude fat content because of the weakening of intermuscular connective tissue by adipose tissue development[17]. The present study suggests that the difference in the shear force of the ST muscle between groups before aging probably resulted from the slight difference in extract lipid content in those muscles. Furthermore, the WBSF in the LL muscle at 2 days and ST muscle at 30 days after slaughter tended to be higher in the hay-fed group than in the concentrate-fed group (Table 2), but there were no significant differences between groups. In general, the muscle of steers that have been fed large amounts of roughage has a higher shear force than that of concentrate-fed steers. Although shear force in the ST muscle of the hay-fed group was higher than that of the concentrate-fed group at 2 days after slaughter, there was no significant difference between groups in either muscle at 30 days after slaughter. These results suggest that a 30-day aging process could eliminate the differences in toughness between the treatments.

The fatty acid compositions of the ST and LL muscles of the hay-fed and concentrate-fed groups are shown in Table 3. Fatty acids in the ST and LL muscles exhibited significantly higher proportions of C15:0, C17:0, and C18:0 in the hay-fed group than in the concentrate-fed group, a result similar to that reported by Muramoto et al. (2005)[16] and Srinivasan et al. (1998)[22]. On the other hand, there was no significant difference in saturated fatty acids (SFA) and polyunsaturated fatty acids (PUFA) in both muscles between the two groups. Furthermore, fatty acids in the LL muscle had significantly lower proportions of C18:1 and

Table 3. Fatty acid composition (%) of total extractable lipids in the *M. longissimus lumborum* (LL) and *M. semitendinosus* (ST) muscles of steers fed grass hay or concentrate

	LL		ST	
	Grass hay	Concentrate	Grass hay	Concentrate
C14:0	2.73±0.21	3.02±0.10	2.18±0.17	2.55±0.11
C14:1	0.78±0.19	1.05±0.03	0.83±0.10	0.97±0.07
C15:0	0.38±0.03	0.30±0.00*	0.38±0.12	0.30±0.00*
C16:0	26.9±0.27	26.4±0.70	24.9±0.20	26.1±0.67
C16:1	3.90±0.47	4.75±0.22	4.53±0.41	5.08±0.24
C17:0	0.93±0.09	0.67±0.03*	0.87±0.06	0.70±0.03*
C17:1	0.75±0.09	0.77±0.05	0.88±0.05	0.83±0.05
C18:0	12.7±1.3	9.30±0.42*	10.2±0.49	8.27±0.26*
C18:1	44.6±0.96	47.8±0.69*	46.4±0.62	47.5±0.78
C18:2n-6	2.05±0.13	2.58±0.13*	2.93±0.37	3.17±0.14
C18:3n-3	0.20±0.00	ND[1)]	0.25±0.02	0.10±0.00*
C20:1	0.23±0.03	0.28±0.03	0.23±0.02	0.25±0.02
C20:3n-6	0.20±0.00	0.10±0.00	0.27±0.06	0.20±0.05
C20:4n-6	0.23±0.05	0.17±0.03	0.60±0.21	0.47±0.11
C22:5n-3	ND[1)]	ND[1)]	0.25±0.05	ND[1)]
Unidentified	3.65±0.14	3.00±0.18	4.47±0.17	3.55±0.16
n-6/n-3	11.9±1.13	-	12.1±0.57	36.0±3.11*
SFA[2)]	43.6±1.43	39.7±1.18	38.5±0.56	37.9±0.88
MUFA[3)]	50.2±1.64	54.6±0.94*	52.8±0.94	54.7±0.88
PUFA[4)]	2.58±0.23	2.68±0.13	4.18±0.74	3.88±0.23

1) ND: not detected, 2) SFA: saturated fatty acid (sum of C14:0, C15:0, C16:0, C17:0, and C18:0), 3) MUFA: monounsaturated fatty acid (sum of C14:1, C16:1, C17:1, C18:1, and C20:1), 4) PUFA: polyunsaturated fatty acid (sum of C18:2, C18:3, C20:3, C20:4, and C22:5). Values are expressed as means ± SEM. *$p < 0.05$

monounsaturated fatty acids (MUFA) in the hay-fed group than in the concentrate-fed group. These results are similar to those reported by Muramoto et al. (2005)[16)] and Srinivasan et al. (1998)[22)]; however, there was no difference in the percentages of C18:1 in muscle between grain-fed and alfalfa silage-fed steers[11)]. While these reports do not indicate constant results from different rearing systems, this result suggests that indoor feeding of a large amount of grass hay to steers would decrease the proportions of C18:1 and MUFA.

C18:3n-3 PUFA was detected in the grass-fed group, but it was not detected in the LL muscle of the concentrate-fed group (Table 3). Furthermore, the ST muscle included a significantly higher content of C18:3n-3 in the hay-fed group than in the concentrate-fed group. Several previous reports have described an increase in C18:3n-3 in alfalfa silage-fed[11)], grass-silage-fed[24)], and pasture-fed[16)] steers compared with concentrate-fed steers. In the present study, indoor feeding of a large amount of grass hay to steers also resulted in an increase in C18:3n-3. The n-3 PUFAs reduce the risk of cardiovascular disease[5)]. The recommended value of the n-6/n-3 ratio, used as an index to maintain human health, is less than 4[6)]. The n-6/n-3 ratio in pasture-fed[16)] and grass silage-fed[24)] steers is also less than 4. Although the n-6/n-3 ratio was not less than 4 in this study, it was significantly lower in the hay-fed group than in the concentrate-fed group. These results suggest that the n-6/n-3 ratio improved more in the hay-fed group than in the concentrate-fed group because of the increase in the proportion of C18:3n-3 in the muscle of grass-fed steers.

In conclusion, this study showed that the meat quality of steers was altered by feeding a large amount of grass hay during the indoor fattening period. In terms of meat quality, this study suggests that the water-holding capacity might be improved in steers fed a large amount of grass hay. Furthermore, the n-6/n-3 ratio decreased in the hay-fed steers compared with that in the concentrate-fed steers. However, there was a reduction in the amount of meat production in the hay-fed steers compared with the concentrate-fed steers.

Acknowledgments

The authors thank the technical staff at WeNARC. This work was supported in part by a Grant-in-Aid from the Ministry of Agriculture, Forestry, and Fisheries of Japan.

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Summary

The objective of this study was to investigate the effect of indoor feeding of large amounts of roughage on carcass composition and meat quality in steers. Twelve Japanese Black steers were randomly separated into hay-fed and concentrate-fed groups. The hay-fed steers were fed grass hay *ad libitum* and concentrate at 2.0 kg/day, whereas the concentrate-fed steers were fed concentrate *ad libitum* and grass hay at 1.5 kg/day. The steers were slaughtered at 28 months of age. Final body weight, daily gain, TDN intake, rib eye area, and rib thickness were greater in the concentrate-fed group than in the hay-fed group ($p < 0.05$). Lipid in muscle was higher in the concentrate-fed group ($p < 0.10$), but protein content was higher in the hay-fed group ($p < 0.05$). Drip loss in muscle after aging was lower in the hay-fed group than in the concentrate-fed group ($p < 0.05$). Although cooking loss after aging was lower in the hay-fed group, there was no significant difference between the groups ($p > 0.05$). Warner-Bratzler shear force in muscle was greater in the hay-fed group before aging ($p < 0.05$), but there was no significant difference from after aging ($p > 0.05$). Monounsaturated fatty acids in muscle were lower in the hay-fed group than in the concentrate-fed group, and saturated and polyunsaturated fatty acids showed no significant difference between the groups. Furthermore, n-3 polyunsaturated fatty acids were detected or increased in the hay-fed group compared with the concentrate-fed group. These results demonstrate that meat quality such as water-holding capacity and n-6/n-3 ratio may be improved by indoor feeding of grass hay.

牧乾草の給与が黒毛和種去勢牛の産肉性，枝肉成績および肉質におよぼす影響

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摘　　要

日本の食料自給率は先進国の中でも最低レベルであり，その向上のためにも飼料自給率の向上が期待されている．飼料自給率向上のためには自給粗飼料の活用が有効であるが，日本の肉用牛の大部分は舎飼で輸入濃厚飼料多給による飼養形態が一般的である．こうした背景の中，舎飼で肉用牛へ牧乾草などの粗飼料を多給した時の肥育・枝肉成績および産肉性について検討された報告は少ない．本研究では，舎飼での牧乾草多給が黒毛和種去勢牛のと体成分および肉質におよぼす影響について明らかにした．

試験区はと畜前 1 年間，大田研究拠点産の牧乾草を飽食かつ濃厚飼料（2kg/day）を制限給与した粗飼料区ならびに肥育全期間，濃厚飼料飽食で牧乾草（1.5kg/day）を給与した濃厚飼料区を設定し，黒毛和種去勢牛（各区 6 頭）を舎飼で供試した．28ヵ月齢でと畜後，枝肉成績の測定，半腱様筋および腰最長筋を採取し，栄養成分，ドリップロス，せん断力価およびクッキングロスを分析した．

1．試験終了時体重，可消化養分総量（TDN）の摂取量および枝肉重量が濃厚飼料区と比較して粗飼料区で有意に少なかった．また，ロース芯面積も濃厚飼料区に対して粗飼料区で有意に小さかった．一方で歩留基準値は試験区間で差は認められなかった．

2．蛋白質含量は濃厚飼料区に対し粗飼料区の半腱様筋で有意な増加が認められた．また，筋肉内脂肪含量は濃厚飼料区で増加傾向が認められたが，試験区間で有意差は認められなかった．筋肉内脂肪酸組成について，濃厚飼料区の腰最長筋で 1 価不飽和脂肪酸含量の有意な増加が認められたが，飽和脂肪酸及び多価不飽和脂肪酸含量はいずれの筋肉においても有意差は認められなかった．n-3系多価不飽和脂肪酸は濃厚飼料区と比較して粗飼料区で増加または検出された．

3．熟成後のドリップロスは濃厚飼料区に対し，粗飼料区の半腱様筋で有意な減少が認められ，さらに，熟成後のクッキングロスは粗飼料区の半腱様筋で減少傾向が認められた．せん断力価について，熟成前では粗飼料区の半腱様筋で有意に高くなったが，熟成後の両筋肉では試験区間で有意差は認められなかった．

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